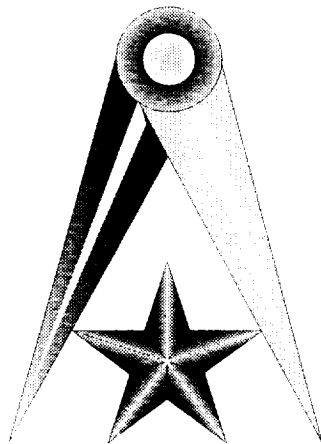


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**HUBBLE SPACE TELESCOPE
ASTROMETRY SCIENCE TEAM**

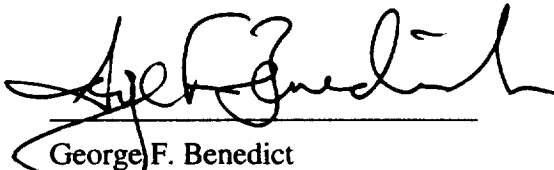
Tenth Semi-annual Progress Report
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Meetings and Travel

Astrometry Science Team meetings were held at STScI on 18 April 1996 and at the McDonald Observatory, Ft. Davis, TX, on 27 June 1996.

Benedict presented a paper on planet searches with FGS 3 at the American Astronomical Society meeting in San Antonio, 16 January 1996. Benedict presented a paper on GTO WFPC-2 observations of NGC 7479 at the Division of Dynamical Astronomy meeting 16 April 1996, held at the Naval Observatory, Washington, DC. Shelus presented a paper on FGS observations of L726-8 at this same meeting and at the American Astronomical Society meeting in Madison, WI 11 June 1996.

Benedict presented public lectures on our HST astrometry planet search to the Austin Astronomical Society (10 May 1996) and to several groups at Kilgore College in Kilgore TX on 3 April 1996.

Story routinely provided STAT representation and input to Guide Star Working Group meetings, Systems Management Board meetings, FGS Servicing Mission meetings, MOSES weekly Performance Reviews, MOSES PCS performance enhancement reviews, OTA Optical TIMS, general Servicing Mission planning sessions, and daily operations meetings, all at GSFC.

Nelan attended several meetings at GSFC which addressed the replacement FGS.

Personnel

Hemenway is finishing his current contractual work for the Astrometry Team and his grant work at the University of Texas. After a long and fruitful association with UT, he is taking up a position as Adjunct Professor at the University of Rhode Island. He will finish his current obligations during a leave of absence from UT until the end of the calendar year, at which time his formal association with UT will end. He will continue his association with the Astrometry Team while at URI.

During the reporting period, research associate Andrew Lalich resigned to take a position in industry. Over the past few years his work on the HIPPARCOS Reference Frame tie has been vital, and we will miss him.

Calibration

McArthur continued reduction of the Fall 1995 OFAD experiments, producing new sets of parameters and coefficients, including a time dependent reduction with ρ_A and k_A variations. She reduced and included in the OFAD all LTSTAB tests. She also updated the high-level pipeline with more features and wrote several Macintosh-based plotting routines to illustrate our results. She has re-reduced older data with the new calibrations.

Nelan routinely retrieves all STAT, selected GO, and Calibration astrometry data from the STScI archives and performs the front-end pipeline data reduction processing, generating compact summary files ready for input to the Austin and Lowell pipelines. McArthur then performs the back-end calibration of all POS mode astrometry data for all STAT, selected GO, and Calibration data sets, while Wasserman and Franz at Lowell carry out similar reductions and quality control checks on TRANS mode data,

Astrometry Anomaly Analysis

Nelan (co-located at STScI) and Story (co-located at GSFC) routinely assessed anomalistic behavior from all GO, GTO, and calibration astrometry pipeline data for all STAT members.

Story (co-located at GSFC) continued in the area of drift analysis, the goal being understanding and removing aero torque contributions from the command frame signal. Unfortunately, inertial motion as measured by the astrometric FGS show incompatibilities with the command frame signals. The premise that command frame drive signals would be commensurate and scaleable with inertial witness motion was found to be false in two specific cases;

- a. V3 axis singular disturbance events associated with rear drum of telescope.
- b. V2/V3 standoff error associated with terminator crossings.

Other than the two noted cases above the approach shows promise. But, until these phenomenon are better understood, the approach for drift removal will not be feasible in it's present conception.

McArthur and graduate student Howell continued to carry out quality control checks by generating overlapping plate reductions for those astrometry data sets that happen to be nearly contiguous in time, and that have similar orientations.

Wasserman and Franz at Lowell carry out quality control checks on all STAT, selected GO, and Calibration TRANS mode data.

GO Support

T. Harrison (NMSU) visited Austin on 30 January for assistance with preparation of a Phase II GO observing proposal to determine parallaxes of dwarf novae.

We routinely processed FGS data for Cycle 5 GO projects 6036, 6037, 6047, 6062 and all CALIBRATION proposals.

Replacement FGS

Story continued support on systems integration/test team for launch preparation of the flight spare. Effort includes evaluating the potential for future astrometric science capability, including developing the astrometric error budget. To this date, all data indicates a strong potential for future scientific use, albeit, data is only inclusive of pickle center.

Nelan assisted HDOS in the reduction of ground test data from the replacement FGS. This assistance was rendered with software developed by Nelan (explicitly for those tests) on data taken in Danbury and later at the VEST at GSFC.

Nelan has extensively reviewed STScI's FGS SMOVII plans and assisted STScI's acting FGS Instrument Scientist with corrections and optimization of several proposals. For example, he re-scripted the 5 orbit FGS 3 mini-OFAD to include an adequate number of check stars measurements, so that drift can be better eliminated from the measured centroids.

GTO Program

Jupiter Relativity Experiment

On 24 September 1995 Jupiter passed within a few seconds of arc of a bright star. The STAT used this rare occurrence to use FGS 3 to measure the gravitational deflection of light by Jupiter. Whipple's analysis has yielded a clear detection of this effect but the quantification of the amount of bending has proved problematic. The polarized reflected and scattered light within the telescope due to the presence of Jupiter was shown by Whipple and Benedict to cause an effect that mimics a time dependent mismatch in the FGS PMTs. This effect distorts the FGS s-curves at the milliarcsecond level and consequently affects the measurement of the light bending. It is still hoped that this effect can be fully understood and removed. Further analysis of the data is on-going.

Low-mass Companion Searches

The team continues its investigations to discover low-mass companions orbiting Proxima Centauri, Barnard's Star, and L726-8. Most of our effort was directed towards L726-8 this reporting period with nine data sets available for analysis.

Shelus, coordinating with Franz, Wasserman, Benedict, McArthur, and Whipple several reduction algorithms were attempted and the results compared. Shelus's analysis efforts were applied mainly via an Excel Solver exposition. Results from all of the analysis models were largely supportive of one another, lending credence to the specific results obtained. A 9-visit observing scenario was constructed for Cycle 6, which commenced at the end of this report period.

Whipple analyzed the L726-8 position mode FGS data to look for astrometric perturbations that would be evidence of a third unseen component of this double star system. Whipple and McArthur transformed the absolute FGS positions of the two components of the double star that were inferred from the transfer mode FGS data by Wasserman and Franz so that these positions were able to be treated as if they were observed in the position mode. They then combined this information with the true position mode observations of the single reference star in the field. Unfortunately, these analyses proved inconclusive due to scale-like changes in the FGS. This is a long recognized problem with the FGS that is usually combated by the use of several reference stars. That strategy was not possible with this field and so the single reference star approach was tried.

Whipple developed a computer program to numerically integrate the equations of motion of the Newtonian three-body problem to model the dynamical evolution of the orbit of possible low-mass companions in the L726-8 system. He used this program to investigate the stability of companion orbits in this binary star system. Regions of stable and unstable initial conditions (orbits) were mapped out. The stable regions were further investigated to differentiate between quasiperiodic and chaotic orbits. This stability analysis is being used by the astrometry team to test the reasonableness of any detected perturbations as well as to get a leg up on the dynamical study of any planet found. In a related manner, this stability analysis is being used by Jefferys and McArthur to form the probability distribution function for their Bayesian analysis of the L726-8 FGS data.

HST- Hipparcos Extragalactic Link

During the reporting period, we ran the final solution for the relationship between the Hipparcos Reference Frame and the ICRS reference system (VLBI based). The following

table gives the values of the parameters and their formal errors. The ϵ are in milliarcseconds at the mean epoch of the HST observations, and the ω are the time derivatives of the ϵ , in milliarcseconds/year. No significant rotation was found from our data at the 2 mas/year level of accuracy. Our data and results are consistent with the other methods' results, and have been incorporated in the final solution for the Hipparcos Catalogue coordinate system. (Other methods included VLBI and other radio interferometry of radio stars, photographic proper motions of Hipparcos stars with respect to galaxies, and analysis of long term time and latitude observations. The system solution from the Hubble data alone is:

Solution for Mean Hubble Space Telescope Epoch = 1994.25

ϵ_1	ϵ_2	ϵ_3	ω_1	ω_2	ω_3
-27.3	-11.5	27.6	-2.3	-1.8	2.7
σ_{ϵ_1}	σ_{ϵ_2}	σ_{ϵ_3}	σ_{ω_1}	σ_{ω_2}	σ_{ω_3}
2.1	1.4	2.1	2.8	1.5	3.4

(these values were truncated for this report.)

We are continuing to analyze the data for possible temporal positional variations of the EGOs. One problem is separating real affects from photon statistics in the fainter EGOs. Also, the photometric calibration of the ND filter should provide information on low count observations, but we find an inconsistent calibration using the Hipparcos magnitudes so far. Dr. Liz Bozyan is continuing this investigation. We are planning to submit a GO proposal to continue the reference frame observations to give us a better time base for the time variable rotation determination.

Ground-based Observations of Radial Velocities

Whipple and Franz had two observing runs, in January and May, on the McDonald Observatory 2.1 m Otto Struve telescope with the Cassegrain echelle spectrograph to make radial velocity observations of many stars in the Hyades cluster and many M-dwarfs that are being observed by the astrometry team with the FGS. The reduction and analyses of these observations are on-going. The radial velocity observations will provide the third component of motion which, when combined with the FGS plane-of-sky observations, will yield complete three dimensional characterizations of the motions of these targets. An excellent example of need for these observations is the L726-8 system. FGS observations alone can detect the existence of a low-mass companion in this binary star system but cannot distinguish about which star the companion orbits. Complementary radial velocity observations will remove that ambiguity.

Hatzes continues his collaboration with an ESO-based group to obtain radial velocities of Proxima Cen and Barnard's Star. For Proxima Cen ten epochs over three years suggest a possible long-term variation. Barnard's Star shows no RV variations greater than 20 m s⁻¹. Observations on both targets will continue through 1996.

Minor Planet Plate Scale

Nelan modified the pipeline to break the observations of solar system objects into small time steps to avoid occasional nonlinearities of motion at the milliarcsecond level that set in after 30 seconds to 1 minute.

Hemenway visited Yale and tested the Yale PDS (with van Altena and John Lee) capabilities for measuring the minor planet plates taken at McDonald Observatory. The results were a success (3 micron measuring uncertainty for large images on some

McDonald plates, with a plate scale of 7.37 arcsec/mm). We are setting up procedures for shipping the plates to Yale on a regular basis. The plates will be measured mainly by Hemenway and Lee.

Galaxy Surface Photometry

Benedict obtained two orbits (2000s, F569W; 1800s, F814W) of WFPC-2 data on NGC 7479 on 16 October 1995 and is nearly finished analyzing the frames. For the PC, 1 pixel = 0.0455 arcsec = 7.1pc

Why is this galaxy interesting? It is isolated, yet morphologically disturbed (both spiral arms and nucleus). The nearest neighbor is more distant than 0.5Mpc. One can detect star formation along the entire bar and in shells on either side of the bar. A rotation curve (from Duval & Monnet 1985. 1985 A&AS, 61, 141) predicts no ILRs. Residuals to this same rotation curve suggest large deviations from circular motion. Athanassoula models (1992. MNRAS, 259, 345) predict streaming motions and dust morphology similar to that seen in ground-based observations. Quillen et al (1995. ApJ, 441, 549) estimate gas inflow rates along the bar of $10^6 \mathcal{M}_\odot \text{ y}^{-1}$

Since a possible interpretation for the morphological and dynamical disturbances is a past or present encounter with another galaxy, we used the McDonald Prime Focus Camera on the 0.8m telescope. We obtained a total of 4.36 hours exposure, in B and V. We find no obvious companions, high or low surface brightness. We do detect galactic cirrus, confirmed by IRAS 100 μ observations.

From the PC data we find the V and I nuclear structure to be different. V-I color index variations are substantial in nuclear structure. We find recent star formation within 0.5 arcsec of the nucleus. We find the reddest object in the frame (hot dust?) within 0.5 arcsec of nucleus. We may see nuclear structure suggestive of a very close-in ILR ring-like morphology with associated new star formation. We attempt to identify the discrete structures near the nucleus. Most knots in PC field are star clusters (fwhm > stellar). We formed a Color-Magnitude diagram from the cluster magnitudes and colors corrected for background contamination. The nuclear components are clearly separated in brightness (but not in color) from other star clusters. Similar objects are found in NGC 7252 (Whitmore et al. 1993. AJ 106, 1354) and NGC 1275 (Holtzman et al. 1992. AJ, 103, 69).

What happens to bar-driven gas inflow? It remains a puzzle. With so much inflow, why isn't NGC 7479 an AGN? Maybe it is? Colleagues have interpreted the nuclear structure as a jet instead of ILR. If this is not a jet we speculate that the inflow might be re-emitted isotropically as a fine, undetectable spray.

Benedict obtained 5 orbits (3700s, F336W; 2500s, F439W; 600s, F569W; 600s, F814W; 600s, F658N) of WFPC-2 data on NGC 4314 on 29 December 1995. We are presently processing and analyzing these frames.

Software

McArthur continued to maintain maintains Pickles and GaussFit.

McArthur continued to provide world-wide support for scores of GaussFit users.

Nelan and McArthur continued to maintain and improve the data reduction software.

Benedict, McArthur and Brayton expanded the STAT WWW home page (<http://clyde.as.utexas.edu>). A previous incarnation was primarily a public relations tool. Our home page now provides useful management information, especially the [current projects](#) link and an up-to-date list of publications resulting from this grant.

Subcontractors

Lowell Observatory

Franz and Wasserman continued work on the reduction, analysis, and interpretation of FGS TRANS-mode data.

Observations obtained of the nearby M-dwarf binary L726-8 (UV Ceti) under GTO Cycle-5 proposal 6271 were analyzed and the resulting component positions (both differential and in pickle coordinates), precise coordinates of the Transfer Function zero crossings, and component magnitude differences were communicated to Peter Shelus for use in orbital analyses and eventual mass/luminosity studies. At the request of UT Austin, Franz and Wasserman also carried out extensive orbital studies of this system, resulting in several orbit revisions as new observations became available.

Observations of the nearby M-dwarf W1062 (GL748) obtained under the Cycle-5 GO proposal 6047 (T. Henry, PI) in 1995, combined with the Cycle 4 observations under AST-GTO proposal 5174, have yielded the first "visual" orbit of this low-mass astrometric binary of $P=2.423 \pm 0.055$ y and $a=0.1462 \pm 0.0007$ arcsec. The largest orbital residual in separation is +2.0 mas; the others lie between -0.5 and +0.2 mas. A poster paper on these results was presented at the San Antonio AAS meeting in January 1996. Two additional observations subsequently obtained, analyzed, and incorporated into a new orbit solution have yielded further improvement to a level where the errors of the orbital elements contribute at most two percent to the error of the total binary mass.

VA351= GH-203 (Total V=13.2) was first resolved as a 51-mas pair of near-equal components on 1994 d45 in the course of our search for binaries among faint probable Hyades cluster members under Cycle-4 GTO proposal 4892. With four additional measures obtained during 1994 d296 through 1996 d78, we achieved a position-angle coverage of 156° , enough to compute a first "visual" orbit of VA351 (and thus of any Hyades cluster member fainter than $V=8.0$ mag) with $P=3.36 \pm 0.12$ y and $a=0.069 \pm 0.001$ arcsec. These results were presented in a poster paper at the AAS meeting at Madison in June 1996.

Franz and Wasserman refined their earlier numerical simulations of the expected astrometric capabilities of a refurbished FGS with near theoretical S-curve characteristics. Given such S-curves, accurate calibrations, and high S/N data, the precision and accuracy of angular separations of binaries will be improved from the current 1 mas to about 0.1 mas at magnitude differences of 0 to 4 mag and at separations of 10 mas or even less. Detection of binaries of such Δm 's will be possible down to 5 mas separation and even below. This work was presented orally at the AAS-DDA meeting at USNO and during the STAT meeting at STScI in April 1996. Details of this investigation were requested by and provided to the Acting FGS Instrument Scientist.

University of Virginia

Attempts are being made to model VV Cephei to produce the transfer scans obtained with HST.

A ROSAT proposal for VV Cephei observations was submitted.

Serious measuring of the Swarthmore plate collection on VV Cephei began in April of this year. Almost 150 plates have been scanned up to the end of the reporting period. Preliminary results look good, so the measuring will be pushed hard through the summer while student help is available.

Work on the Koesters Prism has ceased because the McCormick instrument maker retired as of May 31st.

Yale University

GTO Globular Cluster Internal Motions

Work is continuing on the analysis to determine the limits of astrometric precision obtainable from the PC I images. T. Girard and Y. Li are continuing to explore the systematic trends in the positions determined from the TINY TIM synthetic images as a function of location on the chip and in sub pixel space. The detailed systematic trends in sub pixel space at the center of one PC I chip have been studied by comparing 200 synthetic images that randomly cover the pixel. Systematic trends that exceed 0.1 pixel are apparent. The simulations over the full field of the PC I are in progress.

GTO Hyades Cluster Member FGS Parallaxes

Additional observations were obtained with the FGS of the Hyades Cluster member stars in the GTO project. No progress was made with the parallax determinations since we are awaiting the improvement of the OFAD models and the subsequent re-reduction of the measurements through the STAT pipeline. Considerable progress was made in the observations with the WIYN Hydra spectrograph of the STAT GTO parallax field reference stars. We anticipate that these observations will be complete during early 1997 and that we will be able to provide spectroscopic parallaxes for all of the HST GTO parallax regions.

GTO Binary Star Analysis

Girard and collaborators completed an extensive measurement and analysis of the Procyon system based on 250 photographic plates, visual, coronagraphic and HST PC II observations. They have derived a new mass for Procyon that now agrees with the value predicted by stellar evolution models.

Graduate Student R. Meyer is continuing work on his Ph.D. dissertation in which he is developing methods for the determination of accurate magnitude differences between the components of double stars. He has completed the characterization of the response of the photon counting MAMA detector used for Speckle Interferometric observations at El Leoncito, Argentina and an ICCD detector that will be used in a second instrument now being built. Preliminary results show that he may be able to substantially improve the accuracy of the magnitude difference determinations using his new model. A further goal of the thesis research is to improve the modeling of the FGS Transfer Curve deconvolution so as to derive more accurate magnitude differences.

GTO Parallel Observations

Graduate Student J. Zhang continues to compile the catalogue of Parallel Observations taken during GTO observations.

Hipparcos Link to the Extra-Galactic Reference Frame

The final Link of the Hipparcos proper motion system to the extragalactic system using the absolute proper motions from the Southern Proper Motion program was completed by I. Platais and submitted the Hipparcos Project. Our final SPM Link solution consisted of

4000 SPM absolute proper motions spread over 60 regions in the southern sky for Hipparcos stars. The solutions obtained from the blue and visual plates were in agreement with each other and with the mean of the solutions obtained by the other investigators.

The HST CD ROM Sky Survey

Chun lin Lu has developed a effective star/galaxy classifier for images on the HST CD ROM Sky Survey that is self calibrating. In addition, he, Girard and I. Platais have compared the positions and proper motions obtained from the Southern Proper Motion Survey with those determined from the HST CD ROM Sky Survey and found that there are significant positional errors as a function of magnitude (the "magnitude equation"). It should be possible to correct the Schmidt positions using the SPM data.

The General Catalogue of Trigonometric Stellar Parallaxes, Fourth Edition, 1995.

An announcement was made of the publication on December 25, 1995 of the new edition of the General Catalogue of Trigonometric Stellar Parallaxes, Fourth Edition, 1995 (YPC) by W. van Altena, J. Lee and D. Hoffleit. The two volume set is available for purchase from the Yale Astronomy Department for \$75.00 plus shipping and handling. An example of the data in the YPC was given for the Hyades Cluster and the four preliminary HST FGS parallaxes. The YPC contains the first two HST FGS parallaxes, namely Barnard's Star and Proxima Centauri as published by the Astrometry Science Team!

